Performance of Parametric Wavelength Exchange for Narrow Pulse Width Return-to-Zero Signal

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Abstract *We demonstrate the parametric wavelength exchange for 10-Gb/s RZ and NRZ signals. The narrow pulse width of the exchanged RZ signal indicates that CW or quasi-CW pumps are capable of handling with ultrahigh-speed signal processing.*

Introduction

Parametric wavelength exchange (PWE) relies on four-wave mixing (FWM) phenomenon, where a signal wavelength at λ_{signal} and an idler wavelength at λ_{idler} exchange their power periodically while two strong pumps at λ_{p1} and λ_{p2} are co-propagating in highly-nonlinear dispersion-shifted fibers (HNL-DSF) [1-4]. PWE finds many interesting applications in modern optical networks. For example, it may find applications as optical packet switch or de-multiplexer in optical time-division-multiplexing (OTDM) systems [2, 3]. Due to its intrinsically fast response stemming from fiber, PWE is considered as a promising candidate for ultrahigh-speed (≥160-Gb/s) wavelength conversion and interchange. A pulsed pump-based PWE is used in [3] in order to perform 80-Gb/s OTDM de-multiplexing. However, whether continuous-wave (CW) or quasi-CW pump-based PWE can handle with high-speed OTDM signals has not yet been investigated. In [4], it has been theoretically predicted that signal bandwidth of PWE ranges from a fraction of a nanometer to several nanometers relying on dispersion and nonlinear factors. In this paper, we demonstrate wavelength exchange between a 10-Gb/s RZ signal with 3-ps pulse width and a 10-Gb/s NRZ signal. It verifies that CW or quasi-CW pump-based PWE can indeed handle high-speed signals. In addition, it implies that amplitude modulated CW (i.e. quasi-CW) pumps can perform as control gates in PWE for packet switching high-speed optical signals.

Principle and experimental setup

The signal bandwidth for PWE has been investigated in [4] by using the analytical solution of coupled equations describing the FWM under the assumption of small signal approximation. The half-bandwidth in wavelength units is given by

$$B_{\lambda} = \frac{4\sqrt{3}\gamma P_0}{C^3 \beta_3 \left(\Delta\lambda_s^2 - \Delta\lambda_i^2\right)} \qquad (1)$$

in which $\Delta\omega_s = \omega_{signal} - \omega_0$, $\Delta\omega_i = \omega_{idler} - \omega_0$. γ and β_3 denote the nonlinear coefficient and third order derivative of propagation constant with respect to the zero-dispersion wavelength (ZDW) of the fiber. P_0 is the total input pump power and C is a constant equals 7.84×10^{11} $s^{-1}nm^{-1}$. We consider a fiber with λ_0 = 1541 nm, β_3 = 1.1×10^{-40} s^3m^{-1} and γ = 12 $W^{-1}km^{-1}$. The

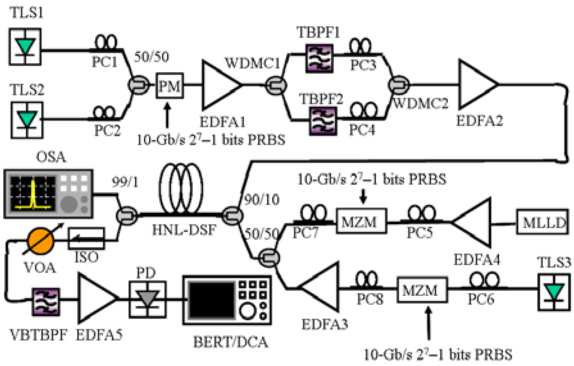

Fig. 1: Experimental setup of the PWE.

signal and idler wavelengths are chosen at 1534 and 1527 nm; while the total input pump power is assumed to be 23 dBm. The calculated 3-dB bandwidth is 3.2 nm, which is wide enough for high-speed signals. In order to verify this prediction, we implement a wavelength exchange for two 10-Gb/s RZ and NRZ signals. The pulse width of the RZ signal used in the experiment is only 3 ps (potential data rate of up to 320 Gb/s) and its spectrum width is around 3 nm. The experimental configuration is shown in Figure 1. The PWE consists of 1-km of HNL-DSF with a zero-dispersion wavelength λ_0 of 1541 nm and a dispersion slope of 0.03 ps / nm^2 km. The fiber nonlinearity coefficient γ is 12 W^{-1} km^{-1}. The two tunable laser sources, TLS1 and TLS2 chosen at 1548 nm and 1555 nm, respectively, are used as pump sources. They are phase-modulated by a 10-Gb/s 2^7-1 pseudo-random bit sequence (PRBS) in order to suppress stimulated Brillouin scattering (SBS). The erbium-doped fiber amplifier (EDFA1) serves as the pre-amplifier to a booster EDFA2. The two tunable band-pass filters (TBPF1 and TBPF2) with 0.8-nm 3-dB bandwidth are inserted after EDFA1 so as to filter out the two pumps separately and reduce amplified spontaneous emission (ASE) noise. Two polarization controller (PC3 and 4) are used to control the state of polarization (SOP) of the two pumps such that orthogonal pump configuration can be provided by minimizing the power of the spurious FWM components. TLS3 is chosen at 1527 nm to serve as NRZ signal channel and it is intensity modulated by a 10-Gb/s 2^7-1 PRBS. It is amplified to

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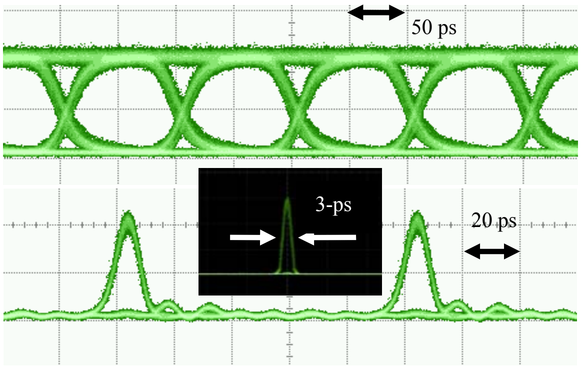

Fig. 2: Eye diagrams observed at 1527 nm (upper); at 1534 nm (lower); before PWE. (inset) RZ signal's eye diagram measured by OSO.

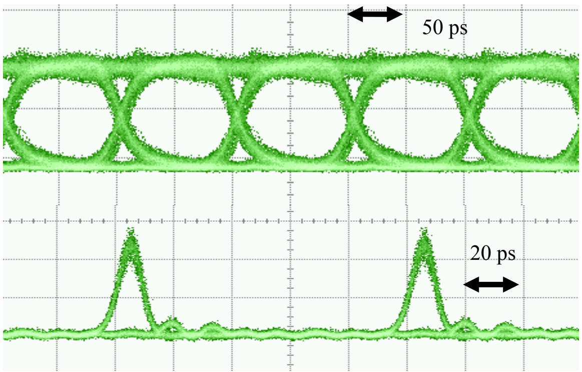

Fig. 3: Eye diagrams observed at 1534 nm (upper); at 1527 nm (lower); after PWE.

an average power of 5 dBm at the input to HNL-DSF by EDFA3. The 10-Gb/s RZ signal is prepared by a mode-lock laser diode (MLLD) at 1534 nm with a Mach-Zehnder modulator (MZM), whose PRBS length is also 2^7-1 bits. The pulse width of the RZ signal is measured to be 3.0-ps by an optical sampling scope (OSO) as shown in the inset of Figure 2, whose operating bandwidth is up to 500-GHz. Due to the low output power from the MLLD (≈ -8 dBm), the output pulse is pre-amplified by EDFA4 before MZM to an average power of 10 dBm. A 50/50 coupler combines the two signals and a 90/10 coupler combines the pumps and signals into the HNL-DSF. 1% of the output power after HNL-DSF is sent to the optical spectrum analyzer (OSA) and the two signals are sent to digital communication analyzer (DCA) and bit-error rate tester (BERT) for waveform and BER measurements after they are separately filtered by a variable bandwidth tunable band-pass filter (VBTBPF) and pre-amplified by EDFA5.

Results and discussion

Figure 2 represents the eye diagrams of the original NRZ and RZ signals before PWE with optical signal-to-noise ratio (OSNR) of 20 and 16 dB, respectively. The original OSNR of the RZ signal is worse than the NRZ signal because its wavelength is close to the edge of MLLD's working wavelength. The exchanged signal after PWE observed at 1534 nm and 1527 nm are shown in Figure 3. The two figures illustrate that

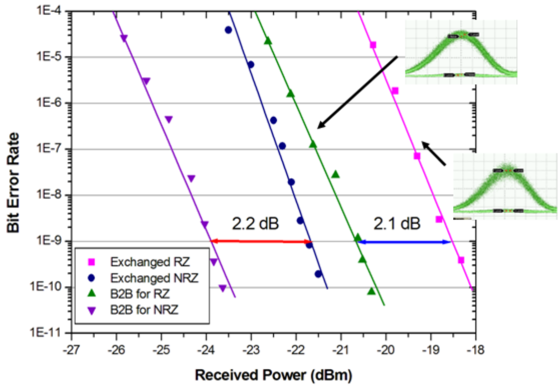

Fig. 4: Measured BER curves for the signals before and after PWE. (insets) Magnified RZ signal's eye diagrams before and after PWE.

the original signals at 1527 nm and 1534 nm are efficiently exchanged to their corresponding idler wavelengths. The output OSNRs are measured to be 15 dB and 11 dB, respectively. The signal quality degradation after PWE is inherited from the ASE noise of the two pumps. To evaluate the performance of the PWE, the receiver sensitivities of the two exchanged signals are measured and compared with their corresponding original signals. The measured BER curves are plotted in Figure 4. At BER of 10^{-9}, the receiver sensitivities of the RZ and NRZ signals are -20.6 dBm and -23.8 dBm, respectively. The power penalty is believed to be caused by the phase dithering of the CW pumps. The CW pumps' dithered phases are transferred to the idler through PWE process. Furthermore, the phase modulation is converted to intensity modulation during filter stages.

Conclusions

We have successfully demonstrated the performance of CW pump-based PWE for a narrow pulse width RZ signal and a NRZ signal. BER of 10^{-9} is achieved with power penalty of ≈ 2dB. Results show that for CW-pump based parametric wavelength exchange, its signal bandwidth is wide enough for ultrahigh-speed optical signal processing.

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